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OPEN HOLE AND POST-IMPACT COMPRESSION FATIGUE OF STITCHED AND UNSTITCHED CARBON/EPOXY COMPOSITES

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Introduction

Compressive strength of laminated composites can be significantly reduced by delaminations. Delaminations can develop at a free edge, particularly at a hole, where interlaminar stresses are very high. Delaminations can also develop from low velocity-impacts. Toughened resins can be used to reduce the initiation and growth of delaminations, but toughened resins are much more expensive than conventional resins. A second approach to improve delamination resistance is through mechanical means such as through-the-thickness stitching. Recent test results [1] show that stitched laminates, made using relatively inexpensive conventional fabric/resin combinations, offer damage tolerance equal to those using toughened matrix materials. To minimize damage from stitching, dry carbon fabrics were stitched with closely spaced heavy threads and than fabricated using resin transfer molding. However, stitching may cause fiber crimping or puncture damage that can reduce fatigue life to unacceptable levels. This investigation evaluates the performance of the stitched uniweave and toughened tape materials and addresses the effects of stitching on compression fatigue life, for open hole specimens and post-impact compression specimens. To this end, a series of post-impact compression fatigue and open hole compression fatigue tests were conducted using specimens made from carbon/epoxy uniweave composite (AS4/3501-6) and a toughened carbon/epoxy tape (IM7/8551-7) without stitching. Results for the stitched material were compared with results for unstitched uniweave AS4/3501-6 [1].

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* Use of manufactures trade named does not constitute endorsement either expressed or implied by the National Aeronautics and Space Administration.

Description of Materials

Toughened IM7/8551-7 Tape

The IM7/8551-7 tape material was also laid up into a 48 ply quasi-isotropic laminate with a $[45°/0°/-45°/90°]_{6S}$ stacking sequence. The IM7 fibers are intermediate modulus carbon fibers and the 8551-7 is a toughened epoxy. The laminate was manufactured by Douglas Aircraft Company from tape prepreg using conventional layup techniques and cured in an autoclave according to manufacture's instructions. This material system was formulated to offer greater interlaminar fracture toughness, and hence more resistance to damage growth, than brittle carbon epoxies. However, it is more expensive than the AS4/3501-6 material. Composite properties are given in Table 1. The unnotched static strengths and average specimen thickness is given in Table 2 for the IM7/8551-7 material.

Stitched AS4/3501-6 Uniweave

A brittle epoxy matrix composite system, AS4/3501-6, was selected for study because it is widely used in tape form. Also the resin is relatively low cost and accommodates the resin transfer molding process. The dry fabric was manufactured by Textile Technologies, Inc. The dry fabric consisted of 95 % carbon fibers and 5 % fiberglass fill yarn by weight. A 225 denier fiberglass yarn was woven in the fill direction to hold the fibers together while stitching. Denier is textiles nomenclature for the weight in grams for a 9000 meter length of thread. A photograph of a specimen made of the uniweave material without stitching is

shown in Figure 1. The fill yarn is the light colored tow and the carbon is the dark colored tow.

Individual layers of fibers were laid up to form a quasi-isotropic laminate with $[45°/0°/-45°/90°]_{6S}$ stacking sequence. These lay-ups were then lock stitched, as shown in Figure 2, with a heavy (3678 denier) fiberglass thread (S-2 Glass 449-1250 untwisted) at 3.2 mm (1/8 in.) row spacing and 3.2 mm per stitch (8 stitches per inch). The stitching was 12 % of the carbon weight. The dry carbon preforms were then impregnated with 3501-6 matrix resin by Douglas Aircraft Company using their patented resin transfer moulding (RTM) process. Composite properties are given in Table 1 for the stitched AS4/3501-6 uniweave material. The unnotched static strength for the stitched uniweave composite is given in Table 2 along with the average specimen thickness. The stitched uniweave composite is about 20% thicker than the toughened tape composite because of the additional fill and stitch fibers. (An increase in fiber content causes an increase in matrix if the fiber weight fraction remains constant.).

Photomicrographs at two different magnification are shown in Figure 3 for a typical stitch site from an untested stitched composite specimen after the 3501-6 matrix material has been removed by heating the specimen to 400° C (752° F) and holding the temperature for three hours. It is evident in this photograph that numerous fibers are broken by the stitching process. The crevasses at each stitch site were filled with resin during RTM. The damaged fibers are potential regions for damage initiation and growth which may contribute to a reduction in static and fatigue strength.

Test Specimens

Open Hole Fatigue Specimens

Approximately 25 mm (1 inch) wide strips that were removed from the sides of the impact panels, as shown in Figure 4, were used to produce the open hole fatigue specimens. The stitching in Figure 4 is not to scale. The average specimen width was 22.1 mm (0.87 in.) for the AS4/3501-6 and 0.95 for the IM7/8551-7. The overall length of the specimen was 10 cm (4 in.) and the unsupported gage length (between grips) was 3.8 cm (1.5 in.). The load bearing ends of each of the specimens were ground flat square and parallel. Each specimen had a 6.35 mm (0.25 in.) hole drilled through it's center. These specimens were made narrower than the NASA open hole compression standard [2] because of a lack of material.

Post-Impact Fatigue Specimens

A NASA [2] standard 17.8 x 25.4 cm (7 x 10 in.) panel was used for the impact study. After impacting, the panels were machined to the NASA standard size 12.7 x 25.4 cm (5 x 10 in.) for compression testing. The load bearing ends of each of the specimens were ground flat square and parallel. Figure 5 shows the size of the specimens.

Test Equipment and Procedure

Open Hole Fatigue Tests

The test fixture used in the open hole fatigue study was originally developed for a compressive loading rate study [3]. This fixture was also used in a previous fatigue study by Lubowinski on stitched materials [4]. The fixture was designed to reduce misalignment which can lead to premature failure. The fixture, shown in Figure 6, has alignment rods running on linear bearings at each of the four corners. The gripping surface has been serrated to transmit load, through shear, on the face of the specimen. The grips also contained end stops that were a few thousandth of an inch thinner that the specimens. These end stops eliminated any slipping of the specimen resulting from the high compressive loads.

Fatigue tests were run at room temperature in a closed-loop servo-hydraulic test machine at a frequency of 10 Hz. All specimens were tested in compression-compression fatigue with an R-ratio (minimum/maximum) of 10. Typical failure sites were sectioned thru, mounted in epoxy, and polished for examination under light microscopy.

Impact Test

The test fixture used for the impact portion of this study was originally developed by NASA Langley for compression after impact loading [2]. This fixture contained a 5 inch by 5 inch opening. A free falling mass impacted the specimen. An illustration of the impactor set-up and test fixture is given in Figure 7. The

impactor consisted of three basic parts: a 51 mm (2 in.) diameter steel rod, an instrumented section of hollow rod, and a 12.7 mm (1/2 in.) diameter spherical tup. The instrumented section of hollow rod, or tup, as shown in Figure 8, contained a piezoelectric accelerometer and four strain gauges for measuring acceleration and impact force. The impact acceleration and impact force were recorded with a digital data acquisition system. The data was then reduced on a desk top PC using commercial software.

The 17.8 x 25.4 cm (7 x 10 in.) panels were mounted in the holder in Figure 7 and the bolts were torqued tight (2.87 J (80 in•lbs)). The instrumented impactor was centered above the panel at the required height to impart the desired impact energy per unit thickness. After the impactor struck the specimen, a piece of wood was quickly moved between the fixture and specimen to prevent the impactor from repeatedly hitting the panel.

An impact energy per unit thickness of 6672 J / m (1500 in•lbs/in), which is a industry standard for evaluating thick, quasi-isotropic laminates, was used. The stitched AS4/3501-6 uniweave panels were impacted at 61.5 J (544 in•lbs) and the IM7/8551-7 tape panels were impacted at 50.2 J (444 in•lbs). These impact energies were chosen to yield the same energy per thickness, because of the the difference in thickness between the IM7/8551-7 and the AS4/3501-6 materials.

Each panel was ultrasonically C-scanned before impact to ensure that the panels were of high quality, free from manufacturing defects that would lead to premature failure. C-scans after impact were used to determine the extent of the impact damage

Post-Impact Fatigue Test

Before each fatigue test was run, a single monotonic excursion was made to maximum load with load and strain recorded on an X-Y chart recorder. The load was recorded directly from the test stand load cell and strain was acquired from a surface mounted strain gage, located immediately above the damage region, in the center of the test specimen. See Figure 5. The slope of the load-versus-strain plot was used to obtain the elastic compression modulus and is reported in Table 3. The fatigue tests were conducted at room temperature in a closed-loop servo-hydraulic test machine at a frequency of 5 Hz. All specimens were loaded in compression-compression fatigue with an R-ratio (minimum/maximum) of 10. The fixture used for the fatigue test was originally developed for static compression loading after impact [2]. Knife-edge supports prevent global buckling while the coupon is being loaded. An illustration of the fixture is shown in Figure 9.

Discussion of Results

The fiber areal weights were similar for each of the materials but the proportion of carbon fibers was less for the stitched uniweave material than for the toughened tape material. The stitched uniweave was 18% thicker on the average than the toughened tape, and as a consequence, it's weight was also greater. By comparing the materials on a stress basis alone, the excess thickness reduces the stress to the point that stitching appears to have a deleterious effect. In order to assess the effects of through the thickness stitching, it was necessary to compare the materials on an equal carbon content basis (equal load per unit width) as well as on an equal stress basis.

Open Hole Fatigue

Maximum compressive load per unit width, N_x is plotted against cycles to failure in Figure 10 for the AS4/3501-6 uniweave composite in stitched and unstitched configurations, and the IM7/8551-7 tape composite. Linear least squares regression fits to the data are also plotted. The unstitched AS4/3501-6 uniweave specimens are made from the same woven preform as the stitched specimens and fabricated using the same RTM process [1]. The thickness of the unstitched uniweave specimens was 7.6 mm as compared to 9.22 mm for the stitched uniweave and 7.45 mm for the toughened tape (table 2). Figure 10 shows that all three of the material configurations experience a reduction in compression strength with constant amplitude compressive fatigue cycles of between 35 and

36% at 10^6 cycles. The fatigue lives are about the same for all of the materials tested, indicating that stitching the material has no deleterious effect, even though stitching may cause additional crimping and results in broken fibers (Figure 3).

Test data for the open hole fatigue specimens of the stitched and unstitched AS4/3501-6 uniweave and the IM7/8551-7 tape composites are given in Table 4 as gross compressive stress, σ_{max}, versus cycles to failure, where the gross compressive stress is

$$|\sigma_{max}| = \frac{P}{W \cdot t} \tag{1}$$

Where P is maximum compressive load

W is specimens width

t is specimen thickness

The data from [1] for the unstitched AS4/3501-6 uniweave are included for convenience of the reader.

Gross compressive stress versus the number of cycles to failure is plotted in Figure 11 for the AS4/3501-6 uniweave in stitched and unstitched configurations, and the IM7/8551-7 tape material. The individual composite densities varied less than 3% so this figure is equivalent to a plot of the specific stress. Therefore, the higher the curve position on this figure, the lighter and stronger the composite. The IM7/8551-7 has the greatest fatigue life per unit weight but only slightly better than the unstitched AS4/3501-6. The greater thickness of the stitched AS4/3501-

6 uniweave caused it's fatigue life to fall well below the other materials. Thus, it appears that the increased thickness from stitching is much more of a penalty in these tests than crimped fibers or puncture type damage from stitching. The 76.2 mm wide specimens in reference [1] give somewhat larger static strength for the stitched fabric and the toughened tape composite than the 25.4 mm wide open hole specimens tested in this study. The fatigue strengths may also be lower for the 25.4 mm wide specimens.

Fatigue Damage Progression - Open Hole

Edge replicating techniques using a substrate of cellulose acetate and a reagent grade acetone were employed to produce replicas. The replicas were taken on the outside edge of the test specimen, adjacent to the hole, at various cycle counts during fatigue loading. The holes were too small to make replicates in them. These edge replicates were then examined under light microscopy for evidence of damage. Visible observations on the surface indicated that damage tended to initiate slightly earlier in the hole than at the edge of the specimen but tended to progress across the width of the specimen at a similar rate. In fact , the damage tended to join midway between the edge and the hole. The damage remained in a narrow region across the net section of the specimen and did not grow along the length.

The photomicrographs in Figures 12 to 15 show the progression of damage through the thickness, at the portion of the straight edge adjacent to the hole, during fatigue loading of the stitched AS4/3501-6 uniweave. Figure 12 is a photomicrograph of the edge at 210k cycles. There is no evidence of damage at

this point in the load history. Figure 13 shows that damage to a depth to 2 mm has initiated at the surface ply free edge within the next 90k cycles. The damage consisted of matrix cracking and delamination. Figure 14 shows that this damage remained mostly unchanged from 300k cycles to 650k cycles, tending to grow only in the vicinity of the surface plies. Although the damage did spread across the width, it did not spread through the thickness until near final rupture. Carbon epoxy materials typically fail under monotonic compressive loading due to matrix cracking and delaminations as well as some fiber breakage [5]. In this material the delaminations were very localized at the hole region and final failure was by shear buckling of the fibers. Others have shown that, although the delaminations start earlier in the fatigue life, they progress at a slow rate in stitched materials [4]. The stitching apparently retards delamination growth by suppressing the opening mode. At some point near failure, matrix cracking and delaminations appear at ply levels well below the surface. This phenomenon can be seen in the photomicrograph in Figure 15, taken at 800k cycles, where failure is only 22k cycles away. The progression of failure in the stitched material is typical of that obtained in tape materials of similar constituents. Thus, stitching does not alter the failure mode of these materials, it only slows it's progression.

Impact Damage

Plots of impact force versus time for both the stitched AS4/3501-6 uniweave and the IM7/8551-7 tape are shown in Figures 16 and 17. The peak impact force was approximately 2041 Kg (4500 lbs) for both materials. The force-time signals for all the impact tests were very consistent. The impactor rebounded on the first collision and was out of the way before the plate rebounded. The high frequency

oscillations throughout the load-time histories are mostly ringing of the impactor and vibrations of the specimens.

After impacting, each panel was ultrasonically C-scaned to examine the extent of damage. Typical C-scan results for both materials are shown in Figures 18 and 19. The damaged area, seen as the white region in the center of these photographs, was measured with the use of a planimeter and is given in Table 3. The damage region in the AS4/3501-6 was about twice as large as in the IM7/8551-7. Stitching limits the damage area in AS4/3501-6 uniweave composite [6], but the toughened resin tape composite had an even smaller damage area. The standard deviation was calculated for each of the impact area data sets. It showed a variation of less than 9% for the AS4/3501-6 and less than 4% for the IM7/8551-7. This low standard deviation indicates that the impacts were consistent and repeatable.

Post-Impact Fatigue

Test data for individual specimens of the stitched AS4/3501-6 uniweave and the toughened IM7/8551-7 tape laminates are given in Table 5. Again, in order to assess the effects of damage due to stitching, the materials were compared on an equal carbon fiber aerial weight basis. Maximum compressive load per unit width is plotted against cycles to failure in Figure 20 for the stitched AS4/3501-6 uniweave and the IM7/8551-7 tape composite. Linear least squares regression fits to the data are also plotted. No data was available for the unstitched AS4/3501-6 uniweave composite. Figure 20 shows that both the stitched material and the toughened system experience a reduction in compression

strength with constant amplitude compressive fatigue cycles of between 33 and 34% at 10^6 cycles. The compression fatigue lives of the stitched AS4/3501-6 are significantly longer than the IM7/8551-7. The static strengths are also larger.

Gross compressive stress is plotted in Figure 21, against cycles to failure for the stitched AS4/3501-6 uniweave and the IM7/8551-7 tape material. Linear least squares regression fits to the data are also plotted. Here, as in Figure 11, the higher the curve position on this figure, the lighter the material. The static strength of the IM7/8551-7 and the stitched AS4/3501-6 are similar. However, the fatigue life of the stitched material is slightly better, even though it is thicker. Thus, the stitched material does not suffer a weight penalty. Recalling that the additional thickness caused the fatigue life of the open hole specimens to fall well below the toughened tape composite (figure 11) then Figure 21 indicates that the effect of additional thickness in the stitched AS4/3501-6 material was not as detrimental for post impact damage life as it is for open hole fatigue life.

Conclusions

An investigation was conducted to evaluate the fatigue performance of a stitched uniweave fabric composite and a more expensive toughened resin tape composite. The effects of stitching on the compression fatigue life of specimens with open holes and impact damage were also examined for the uniweave fabric.

The stitched uniweave composite were thicker than the tape composite because of the additional fill and stitch yarns. For open hole specimens, compared on a stress basis, the fatigue lives of the stitched uniweave composite were reduced in proportion to the increase in thickness. Hence, there was no apparent benefit from stitching. For open hole specimens, compared on equal carbon fiber aerial weight basis, the compressive static and fatigue strengths of the stitched and unstitched fabric composite and the toughened tape composite were about equal. Thus, comparisons based on an equal carbon content indicate that the crimp and puncture type damage from the stitching had no net effect on the compression fatigue strength. For impact damage, compared on equal carbon fiber aerial weight and impact energy level, the compressive static and fatigue strengths of the stitched uniweave composite were greater than those of the toughened tape composite. The toughened tape composite was a little more resistant to initial impact, but the stitched uniweave composite was considerably more damage tolerant. Thus, the impacted uniweave composite did not suffer a weight penalty, despite the increase in thickness. Therefor, it appears that the increase in thickness from stitching is much more of a penalty than crimped fibers or puncture type damage from stitching.

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5. Guynn, E.G., and Bradley, W.L., "Measurements of the Stress Supported by the Crush Zone in Open Hole Composite Laminates Loaded in Compression," Journal of Reinforced and Plastics and Composites, volume 8, number 2, March 1989, pp.133-149.

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Table 1: Composite Properties for Stitched AS4/3501-6 uniweave and Unstitched IM7/8551-7 tape.

COMPOSITE PROPERTIES		AS4/3501-6 Stitched	IM7/8551-7 Unstitched
Carbon Fiber Areal Weight	(g m^{-2})	157	145
Total Fiber Areal Weight, TFAW	(g m^{-2})	171	145
Weight Fractions from acid digestion		62.5	61.9
Carbon Fiber Density, ρ_f	(g cm^{-3})	1.78	1.78
Resin Density, ρ_r	(g cm^{-3})	1.27	1.27
Composite Density, ρ_c	(g cm^{-3})	1.59	1.55

Table 2: Average Thickness and Unnotched Static Compressive Strengths for Stitched AS4/3501-6 uniweave and unstitched IM7/8551-7 tape specimens.

Material System	Thickness (mm)	Unnotched Strength, MPa
AS4/3501-6 Stitched Uniweave	9.22	472.5
IM7/8551-7 Unstitched Tape	7.45	620.0

Table 3: Damage Area and Elastic Modulus for Stitched AS4/3501-6 uniweave and Unstitched IM7/8551-7 Tape.

AS4/3501-6 Uniweave

Stitched

Panel ID	Damage Area cm^2	Compression Modulus GPa
A01	18.85	49
A02	20.14	43
A03	18.56	42
A04	22.12	46
A05	18.71	51
A06	22.32	50
Std. Dev.	1.72	3.7
Mean	20.12	46.9

IM7/8551-7 Tape

Unstitched

Panel ID	Damage Area cm^2	Compression Modulus GPa
B01	10.04	54
B02	9.84	53
B03	10.66	55
B04	10.27	55
B05	10.36	55
B06	9.65	56
Std. Dev.	0.36	0.8
Mean	10.13	54.5

Table 4: Open Hole Static Strengths and Compression Fatigue Data for Stitched and Unstitched AS4/3501-6 Uniweave and Unstitched IM7/8551-7 Tape.

AS4/3501-6 Stitched

Compression Stress, MPa	Cycles
258.96	1
202.07	3160
195.52	2.51E4
195.52	3.63E4
175.79	5.22E4
173.10	3.08E4
166.97	1.08E6
166.83	8.22E5
159.03	5.00E6 *

AS4/3501-6 Unstitched [1]

Compression Stress, MPa	Cycles
317.17	1
258.62	2506
224.14	7860
206.90	1.12E5
189.66	4.37E6

IM7/8551-7 Unstitched

Compression Stress, MPa	Cycles
298.00	1
233.52	5.77E4
228.21	1.27E5
223.79	1.51E5
223.52	1.45E5
214.76	5.46E5
218.97	1.39E6
213.66	4.16E5
209.66	6.56E5
203.52	3.00E6*

* Signifies Runout

Table 5: Post Impact Static Strengths and Compression Fatigue Data for Stitched AS4/3501-6 Uniweave and Toughened IM7/8551-7 Tape.

AS4/3501-6

Stitched

Stress, MPa	Cycles
343.45	1
250.34	2.92E4
250.34	1.26E5
238.97	1.29E4
238.97	1.09E5
227.59	1.21E6
227.59	1.37E6

IM7/8551-7

Unstitched

Stress, MPa	Cycles
334.41	1
250.34	7050
238.97	4.81E4
227.59	3.57E4
227.59	7.79E4
227.59	3.01E5

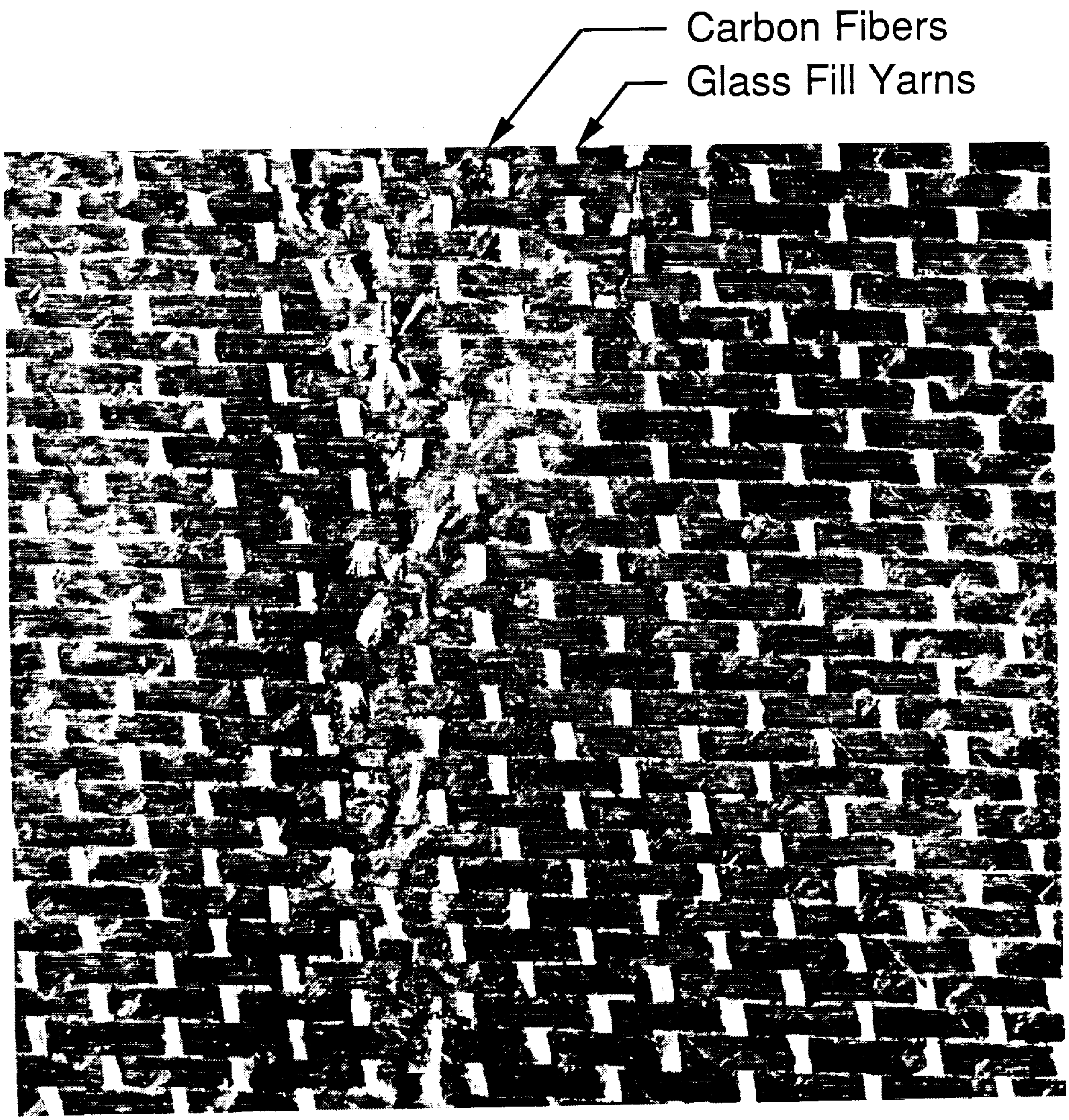


Figure 1: Photograph of an unstitched uniweave specimen

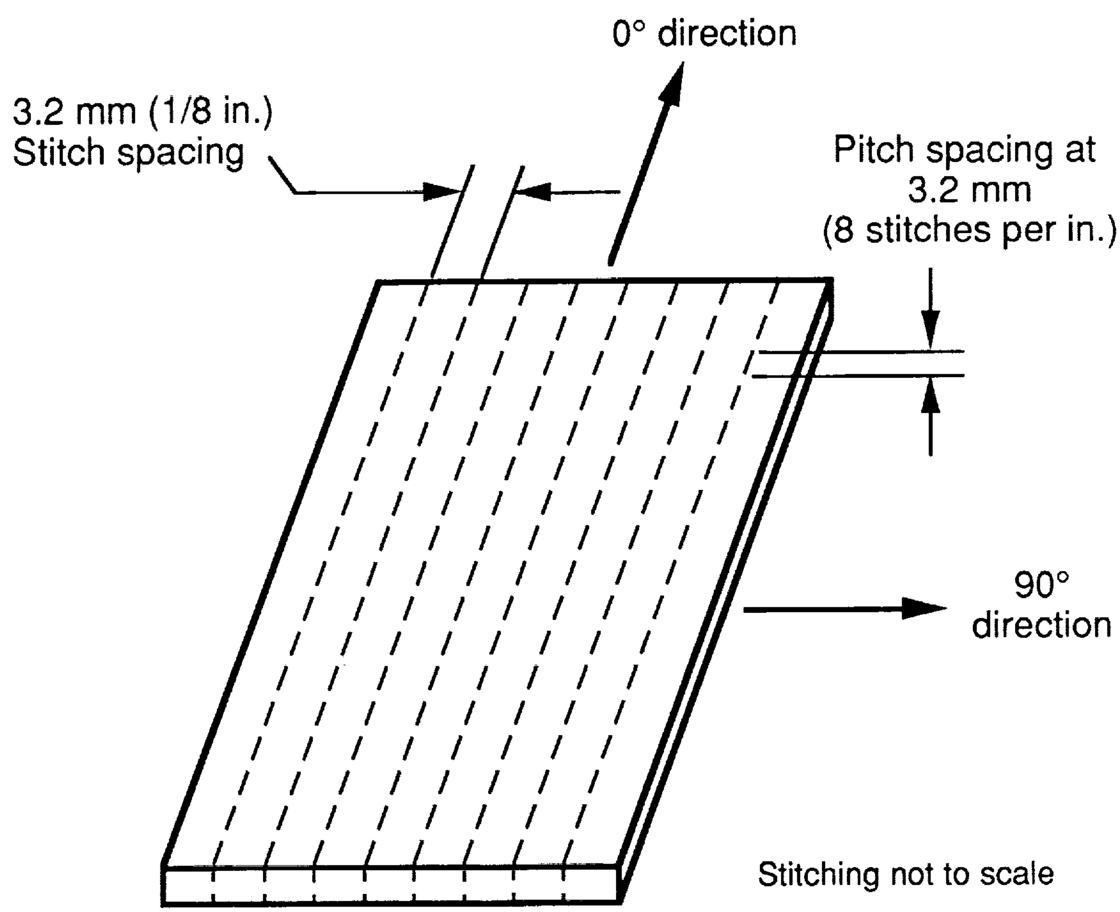
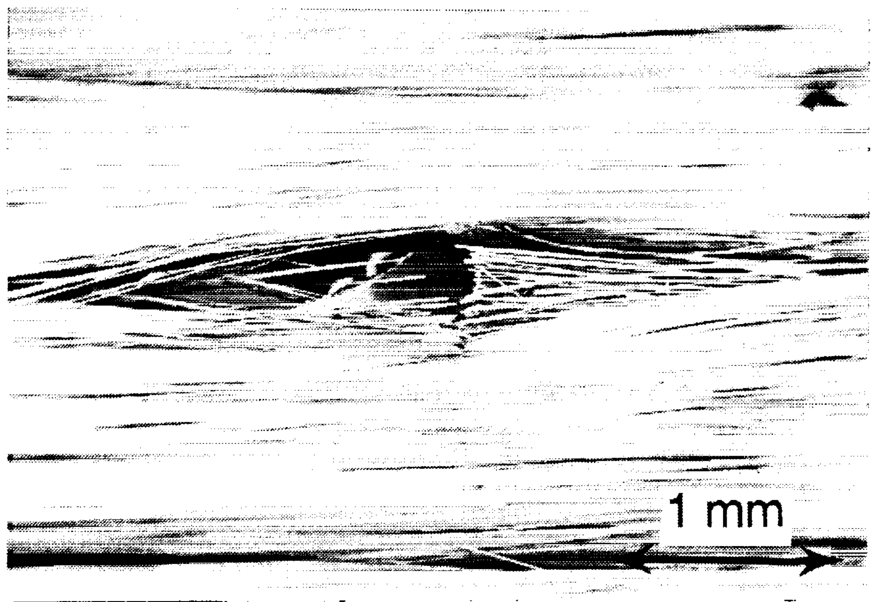
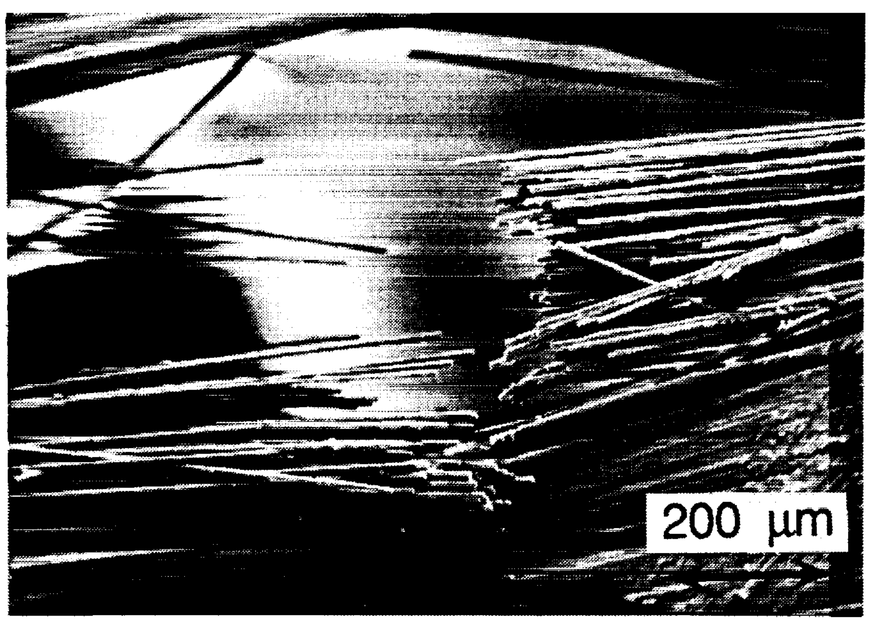


Figure 2: An illustration of the AS4/3501-6 Carbon Epoxy Laminate with unidirectional stitching



(a) Low magnification.



(a) High magnification.

Figure 3: Photomicrograph of a stitch site from AS4/3501-6 after pyrolysis

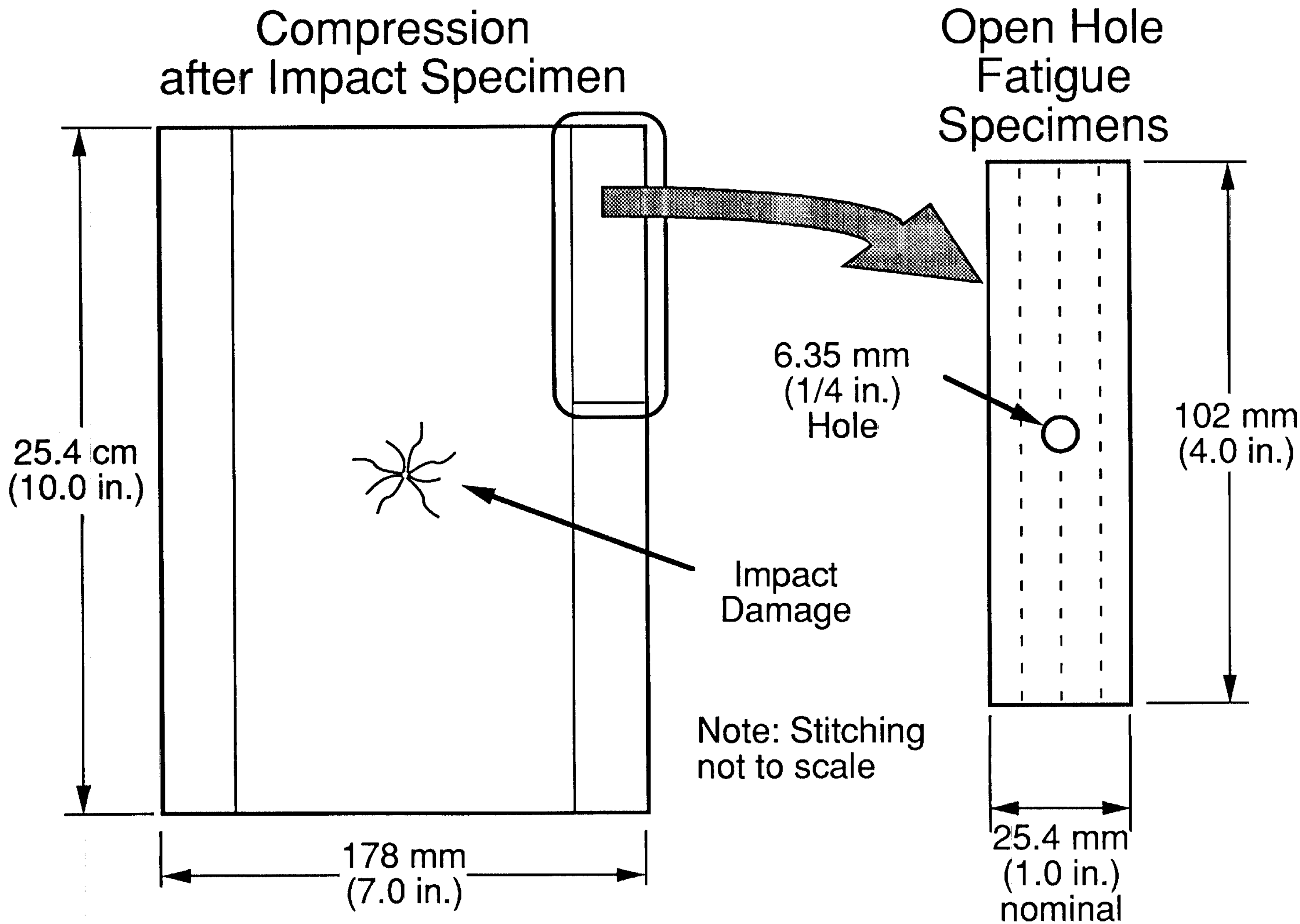


Figure 4: An Illustration of the Open Hole Specimen Fabrication

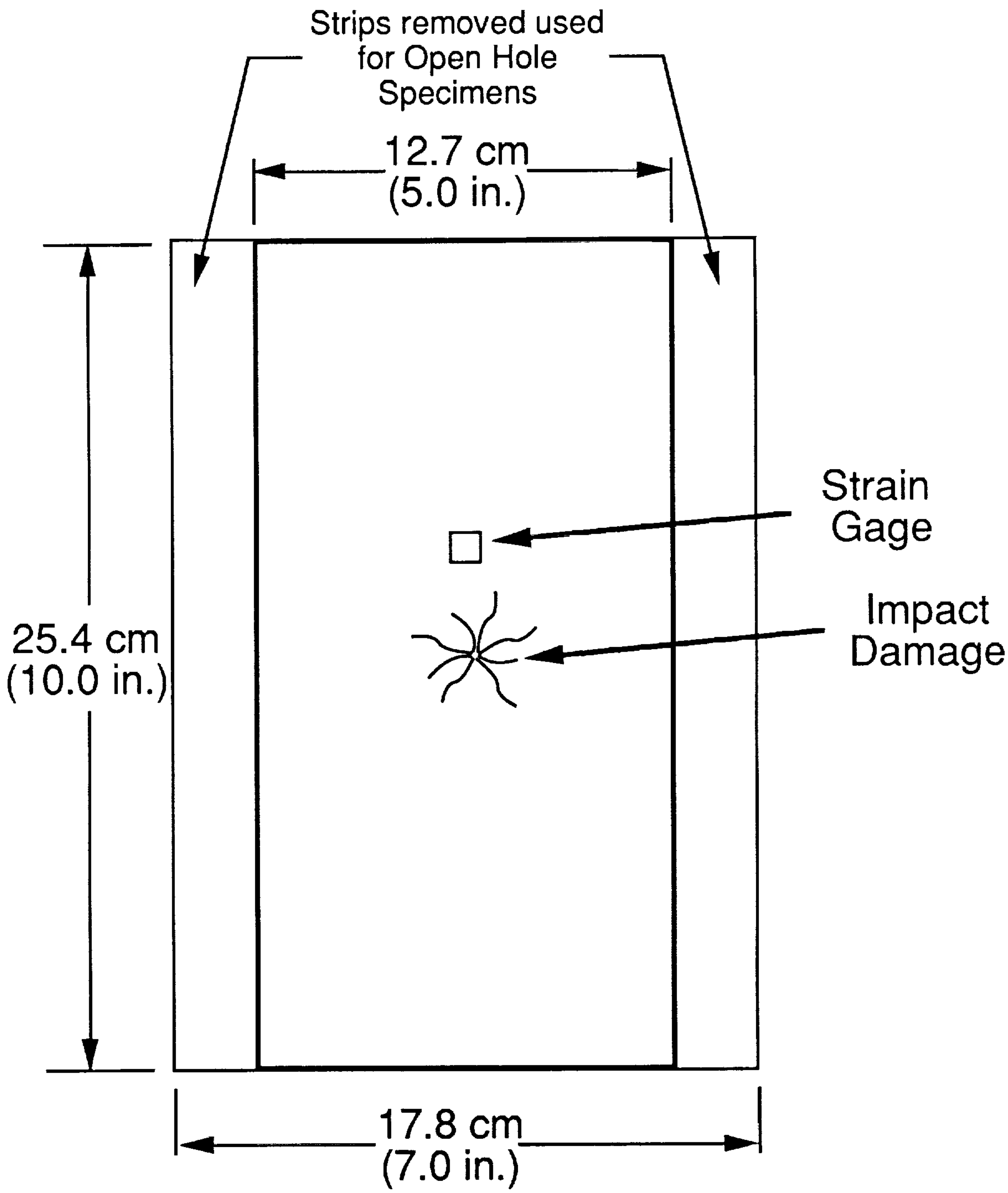


Figure 5: A drawing of Post-Impact Fatigue Test Specimen Dimensions

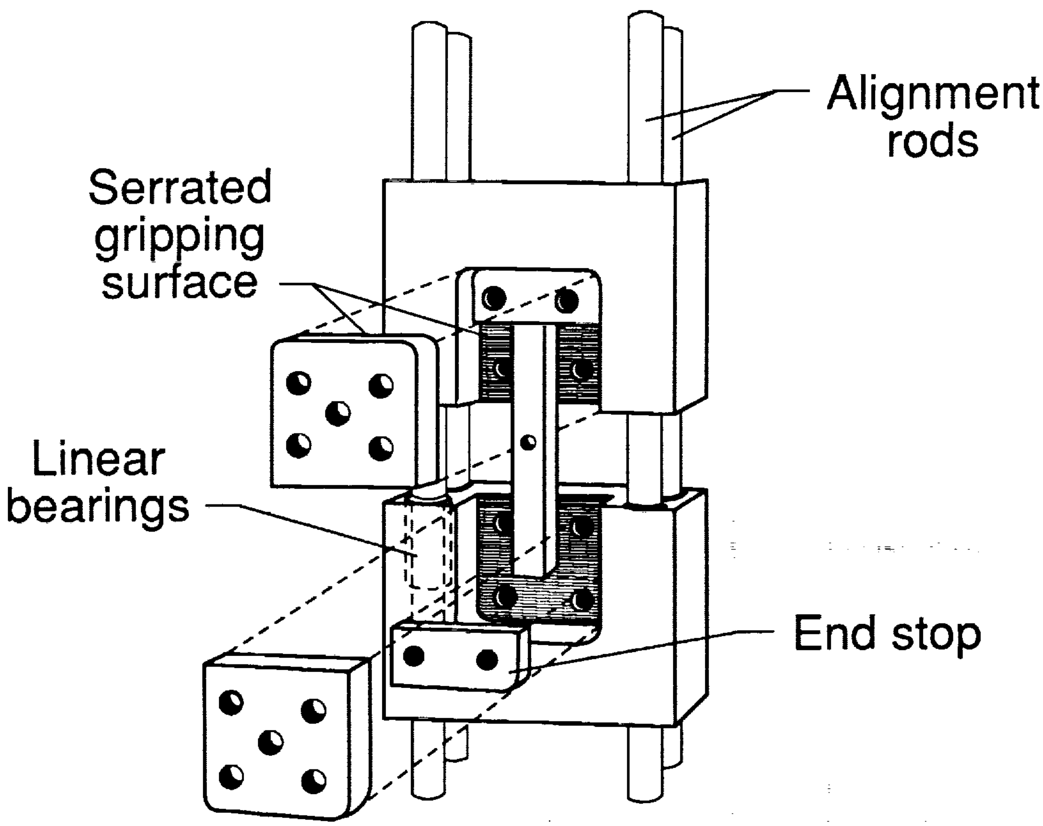


Figure 6: Open Hole Compression Fatigue Test Fixture

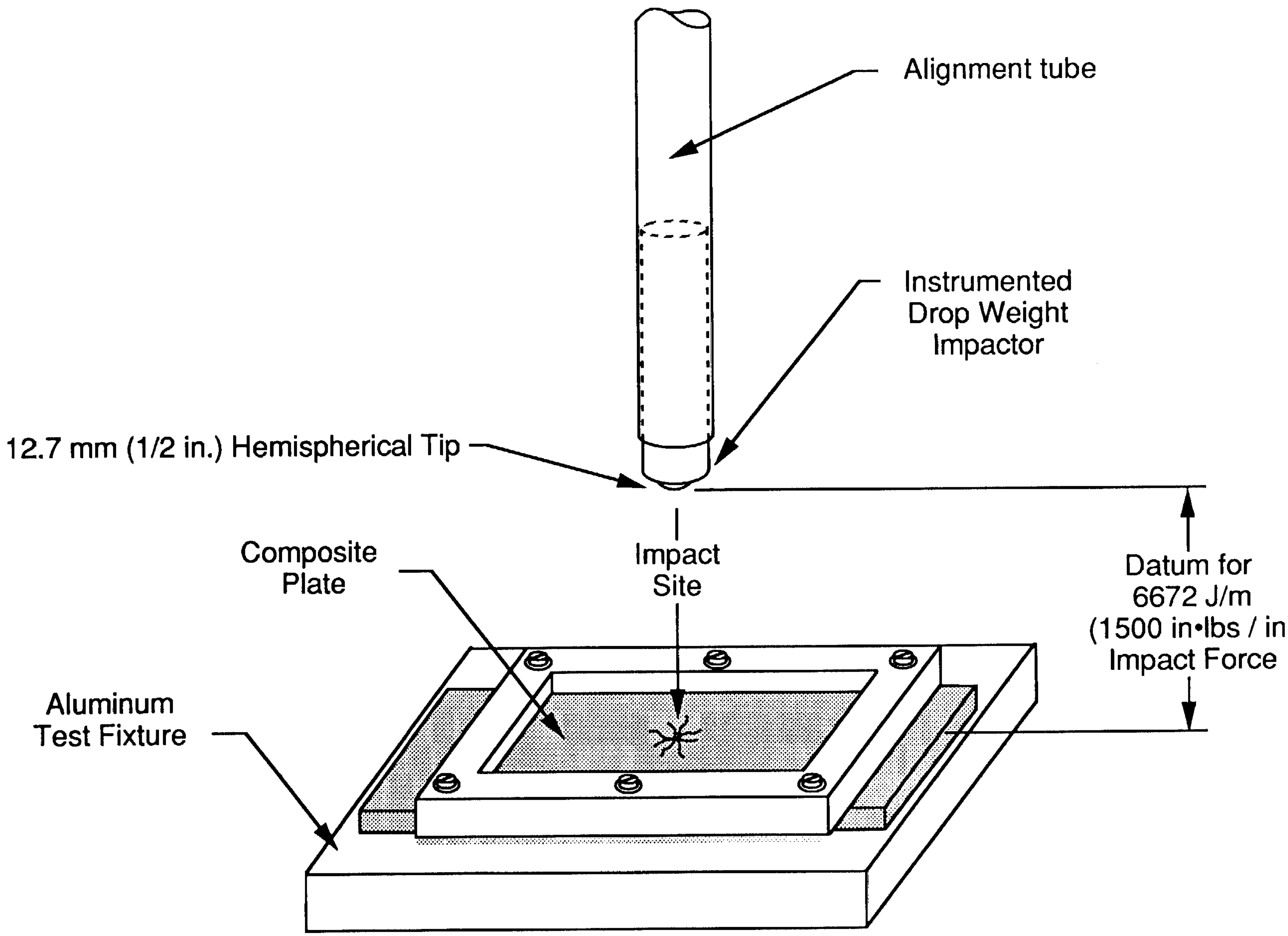


Figure 7: Impacting of Composite Panels

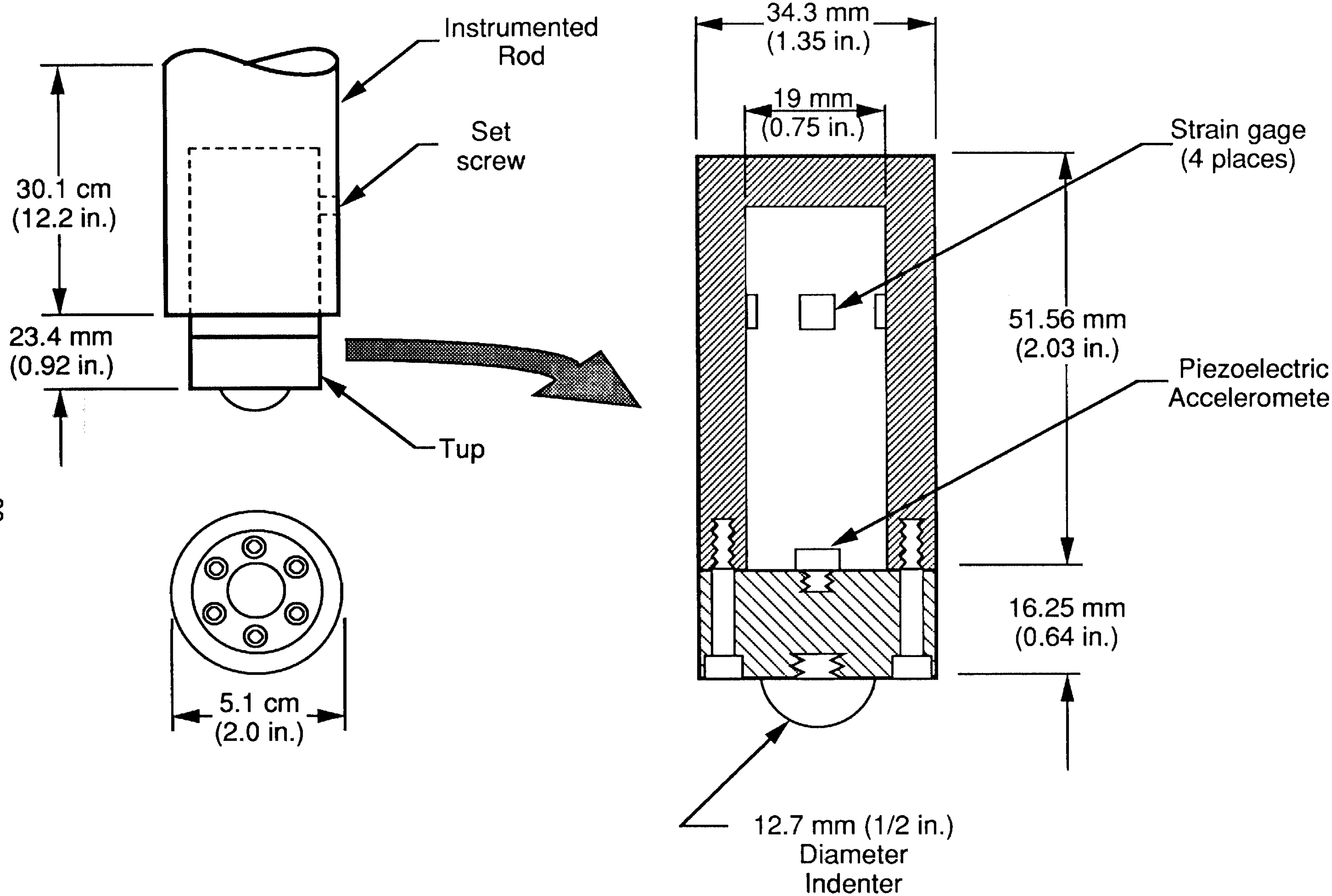


Figure 8: Sketch of Instrumented Impactor Tup

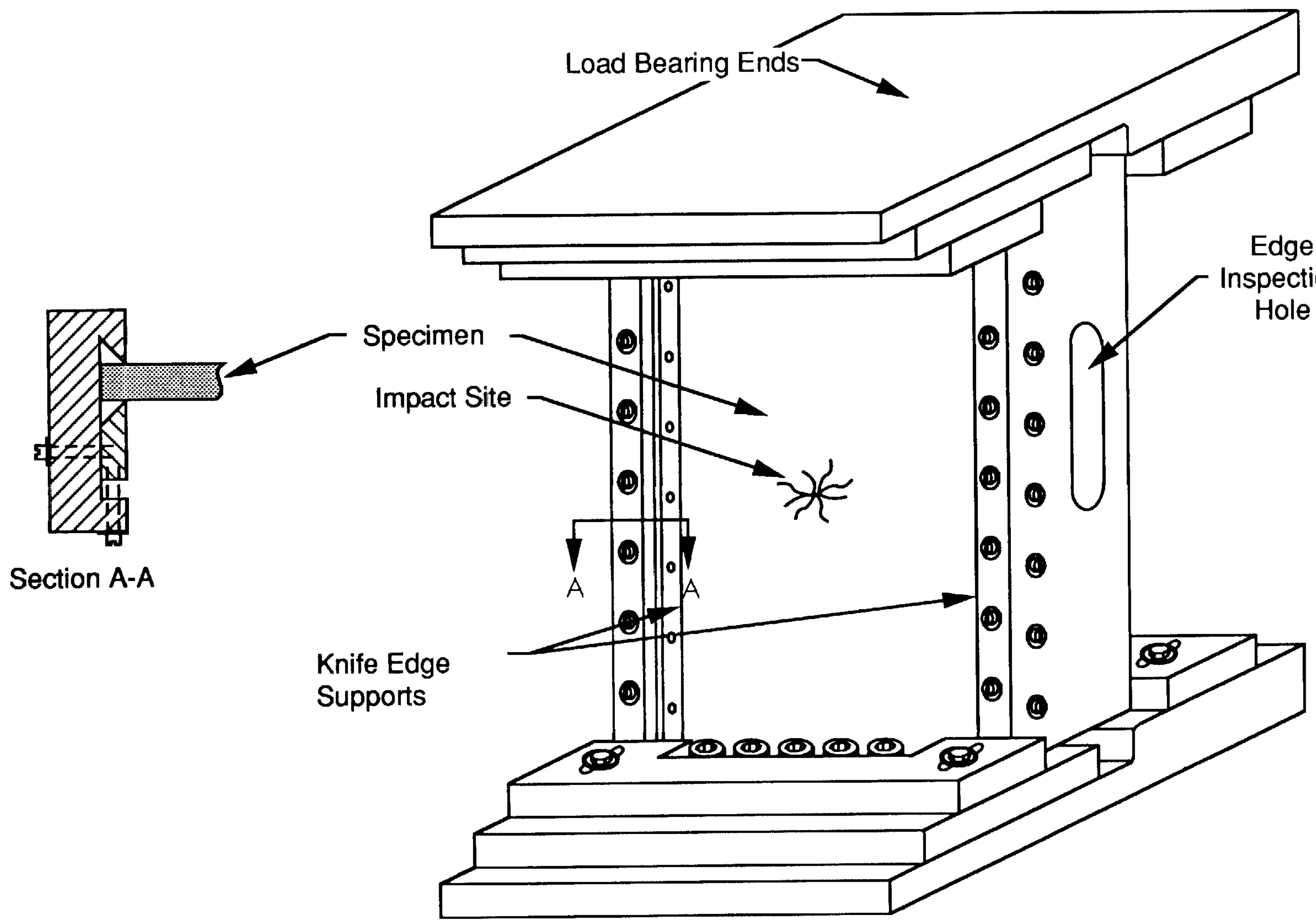


Figure 9: Post-Impact Compression Fatigue Test Fixture

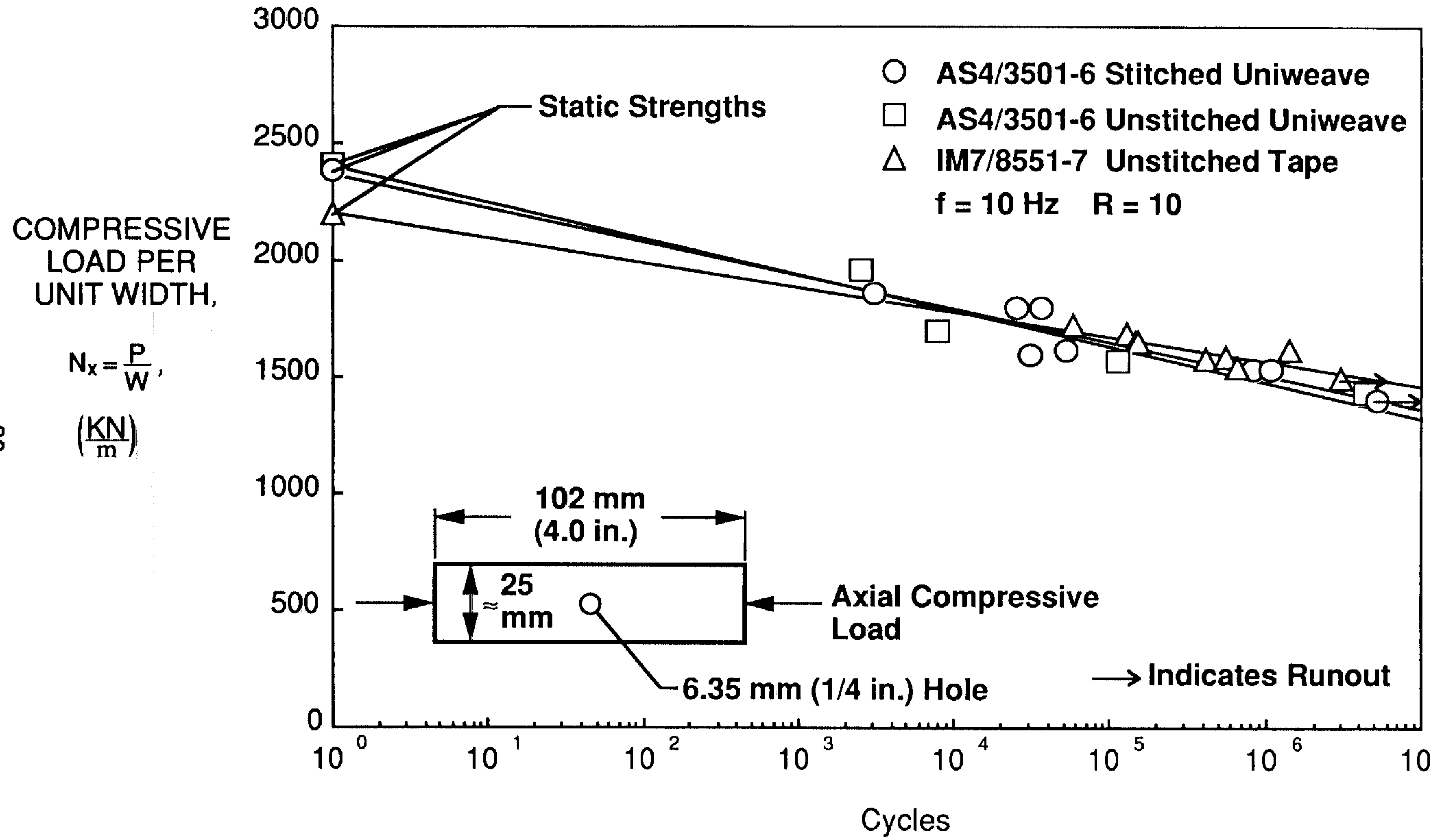


Figure 10: A Plot of Load per Unit Width Versus Cycles for Open Hole Compression Specimens

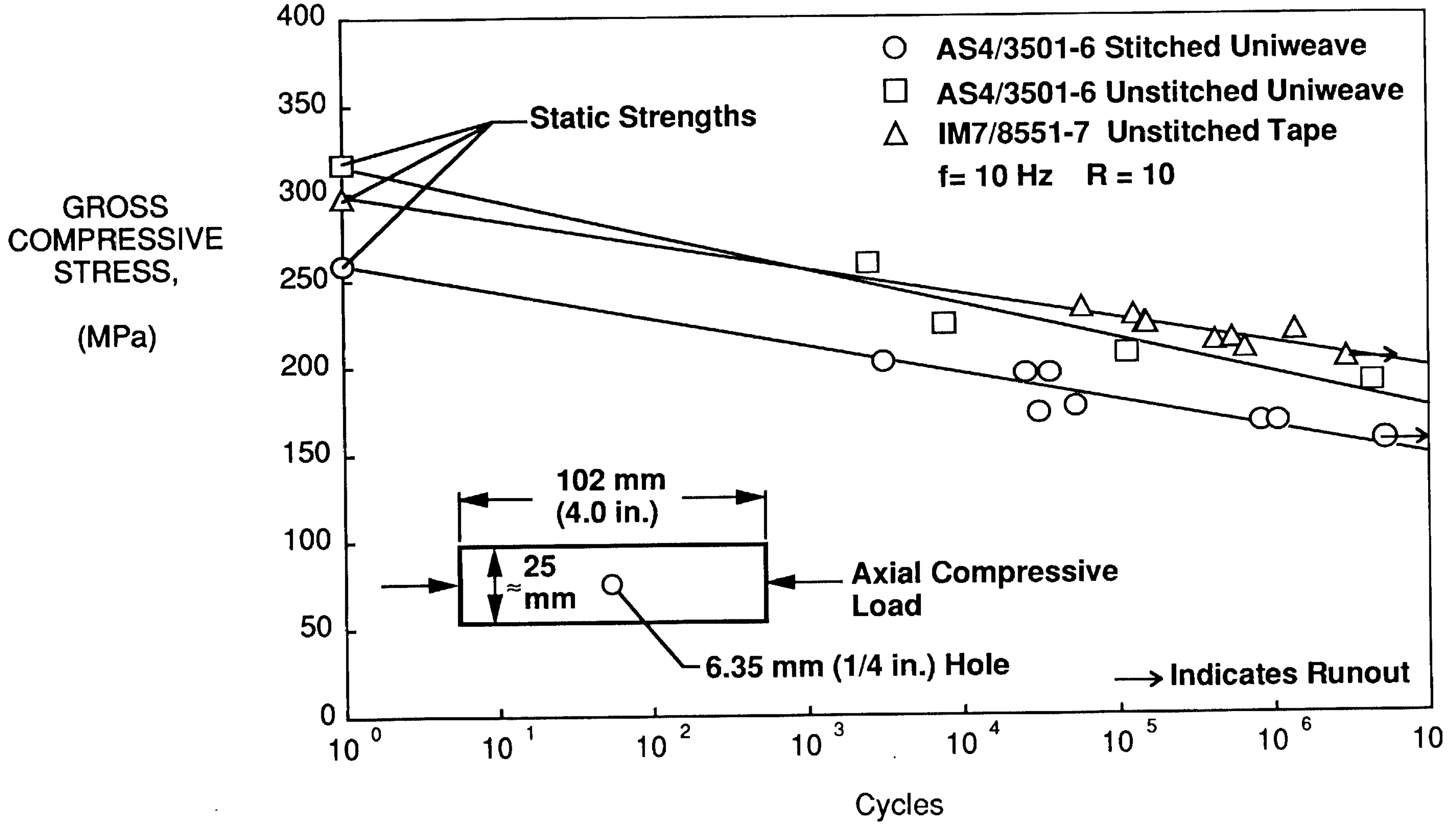


Figure 11: A Plot of Gross Compressive Stress versus Cycles for Open Hole Compression Specimens

Figure 12: Photomicrograph of stitched AS4/3501-6 after 210,000 cycles.
R = 10, 167 MPa Maximum Compressive Stress, 822,000 Total Cycles to Failure

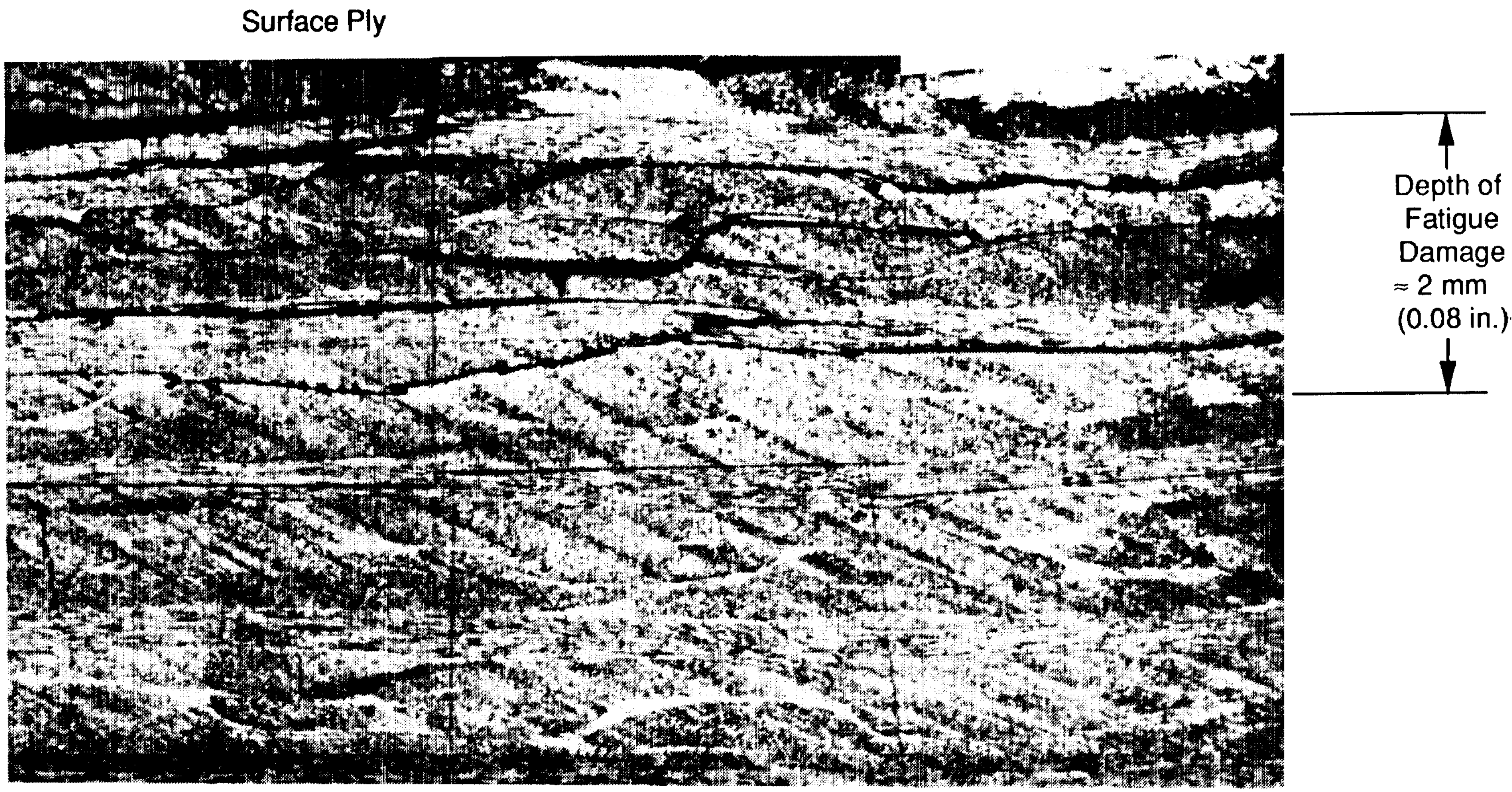


Figure 13: Photomicrograph of stitched AS4/3501-6 after 300,000 cycles.
R = 10, 167 MPa Maximum Compressive Stress, 822,000 Total Cycles to Failure

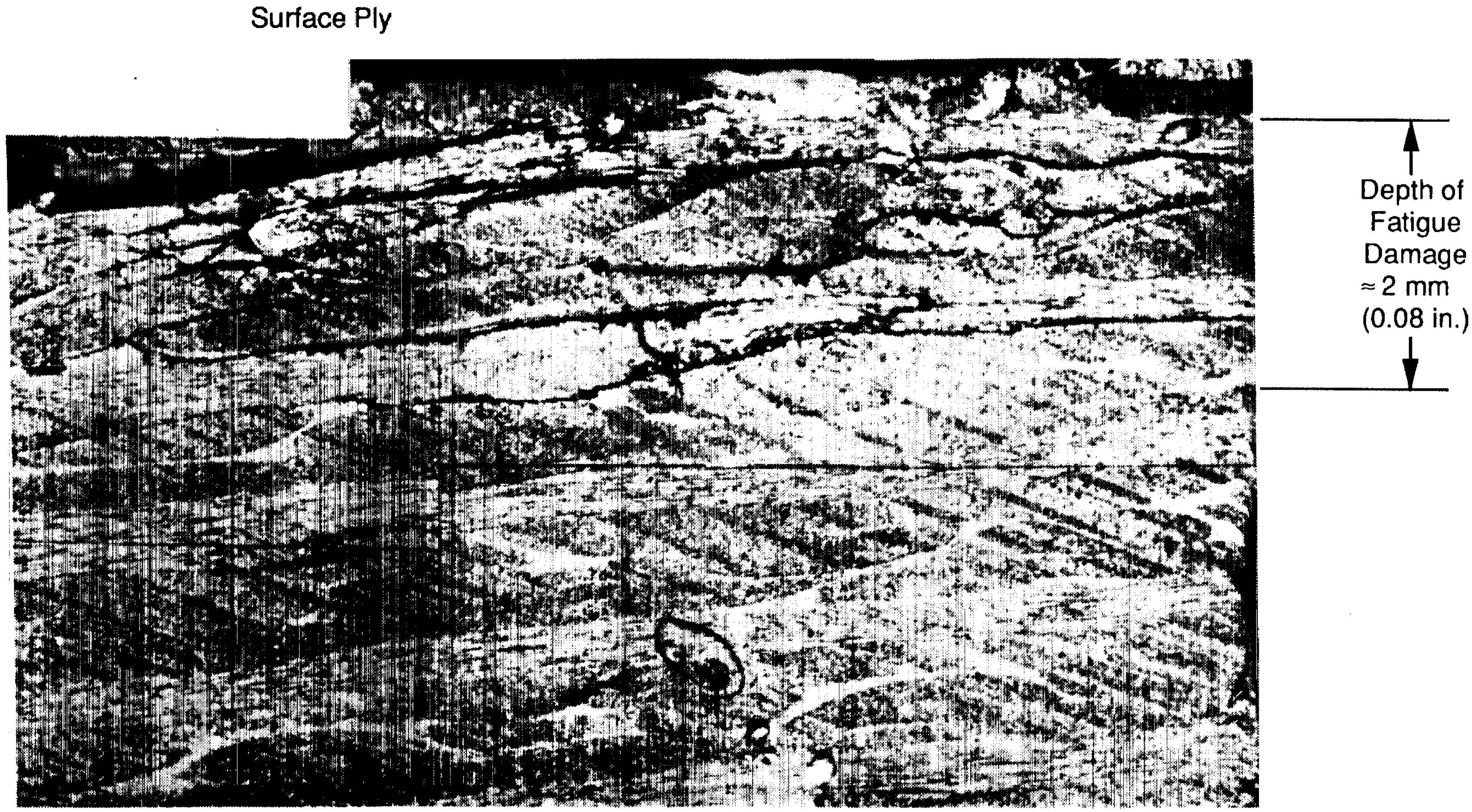


Figure 14: Photomicrograph of stitched AS4/3501-6 after 650,000 cycles.
R = 10, 167 MPa Maximum Compressive Stress, 822,000 Total Cycles to Failure

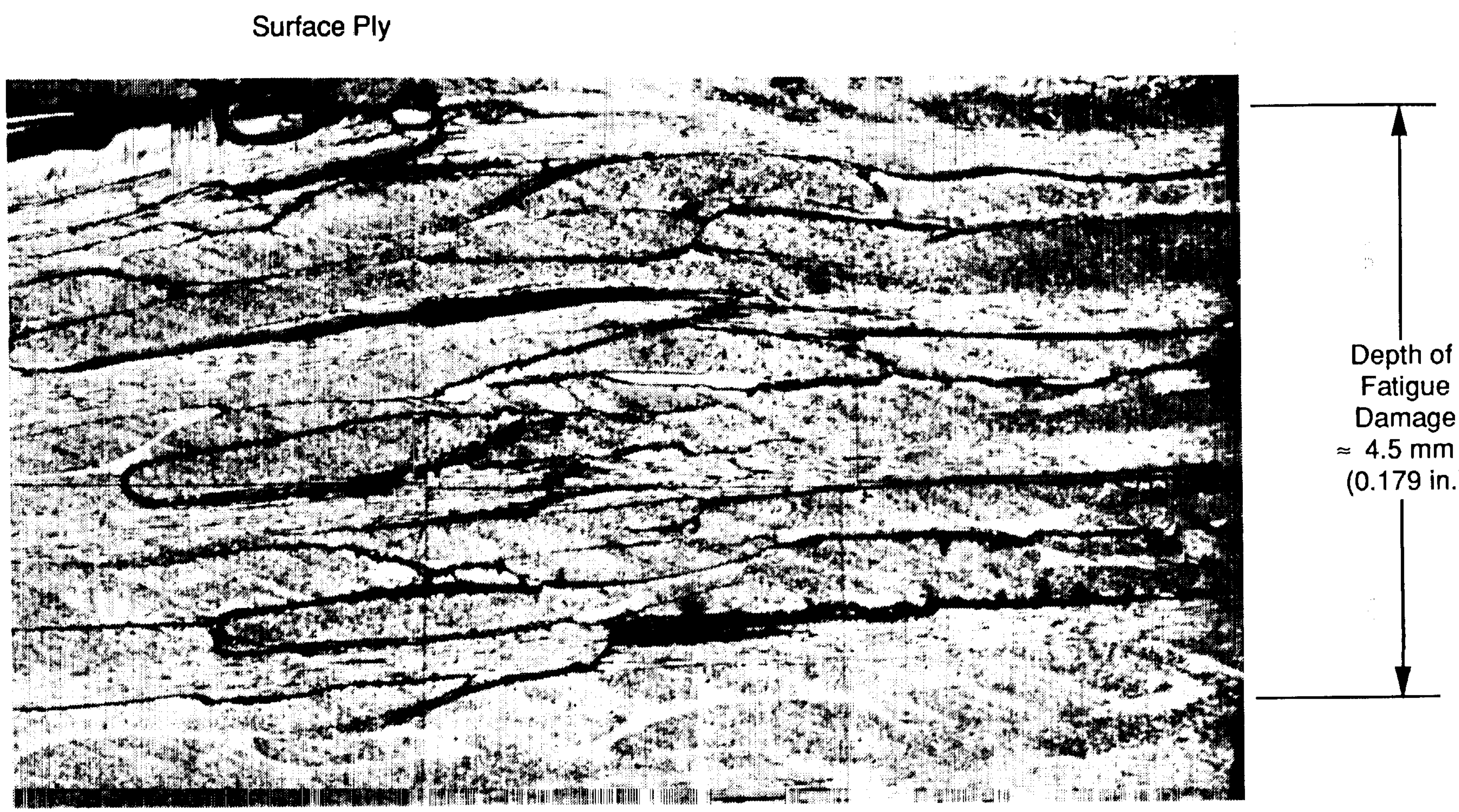


Figure 15: Photomicrograph of stitched AS4/3501-6 after 800,000 cycles.
R = 10, 167 MPa Maximum Compressive Stress, 822,000 Total Cycles to Failure

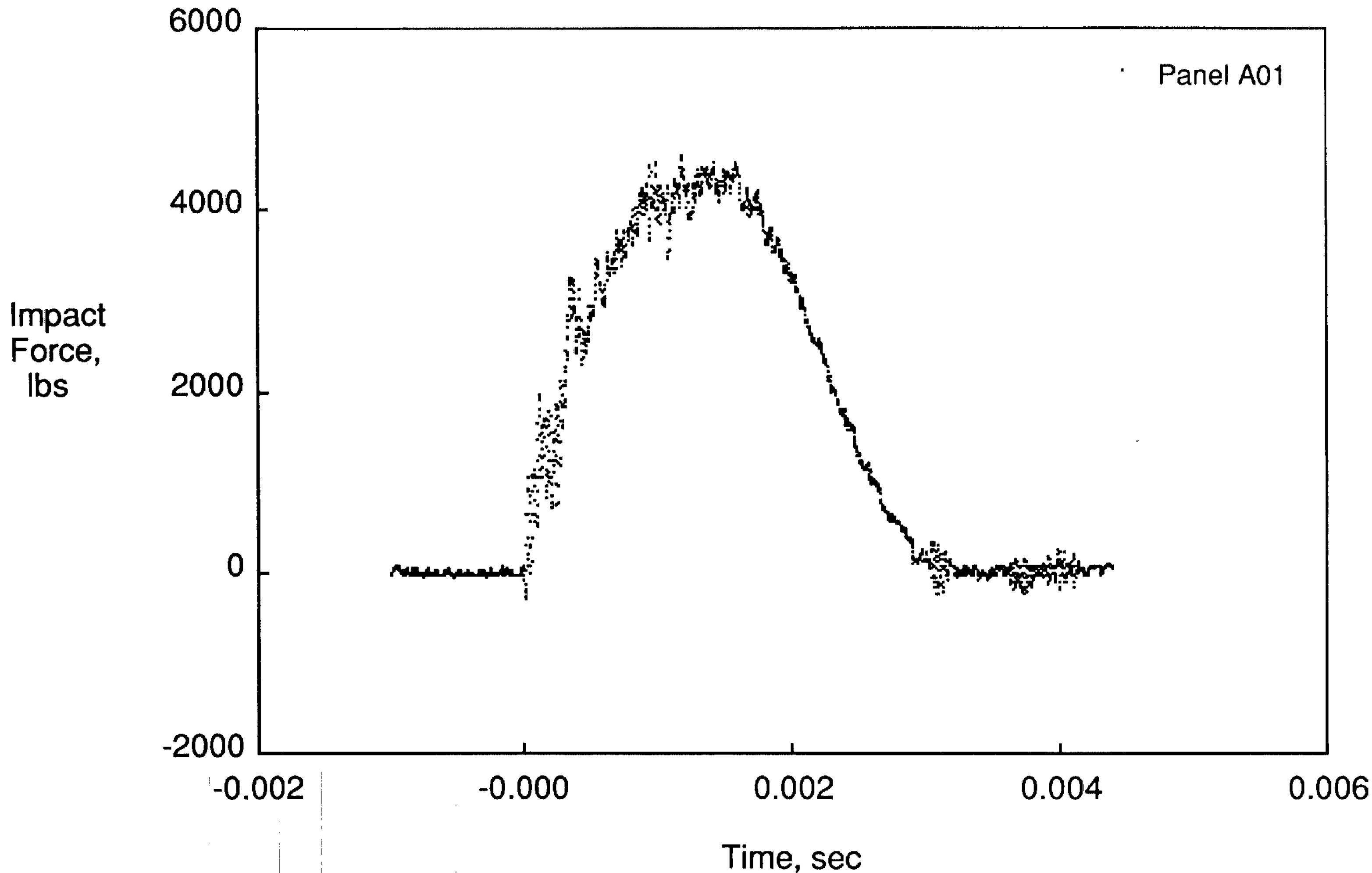


Figure 16: A plot of impact force versus time for stitched AS4/3501-6 (544 in•lbs)

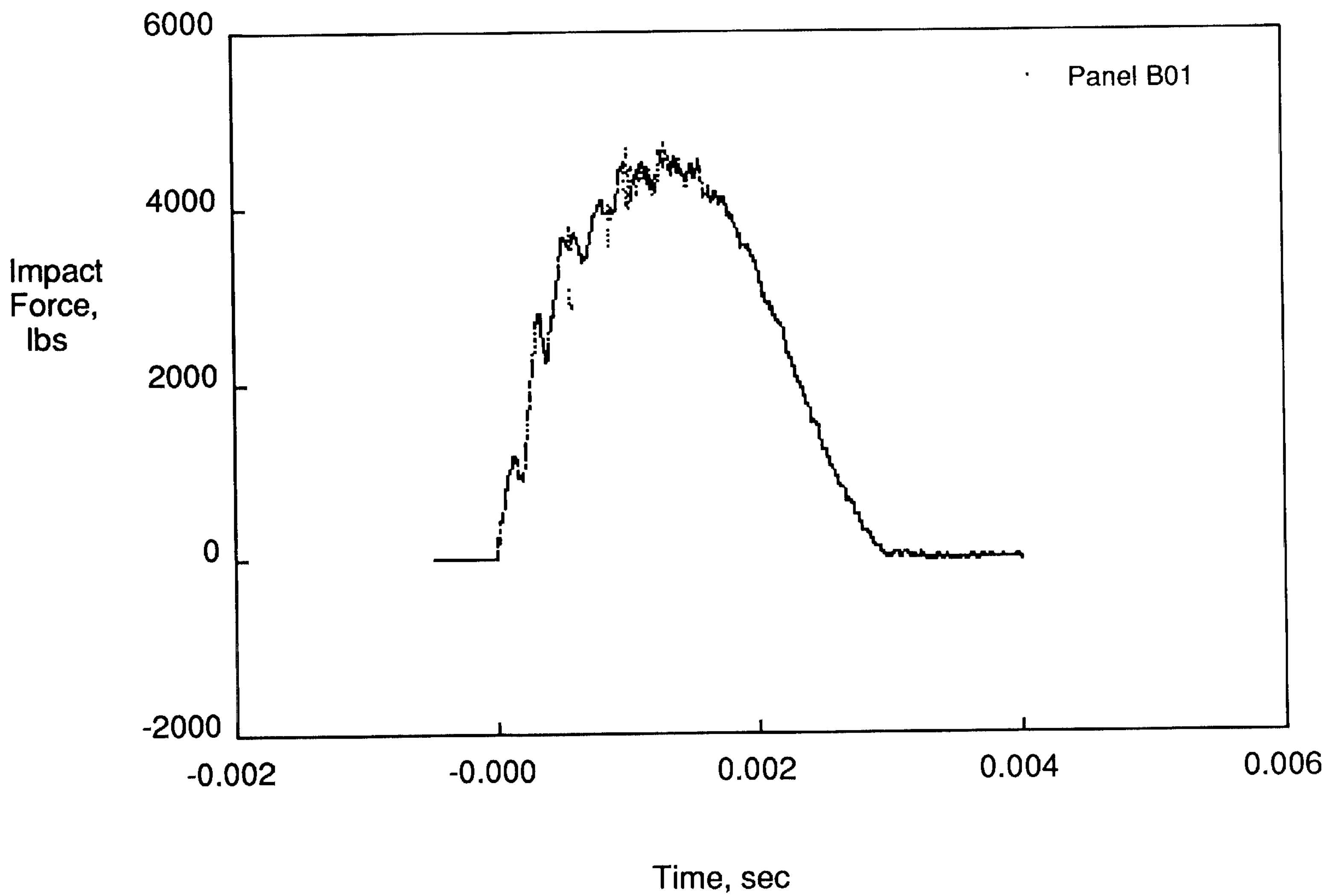


Figure 17: A plot of impact force versus time for IM7/8551-7 (444 in•lbs)

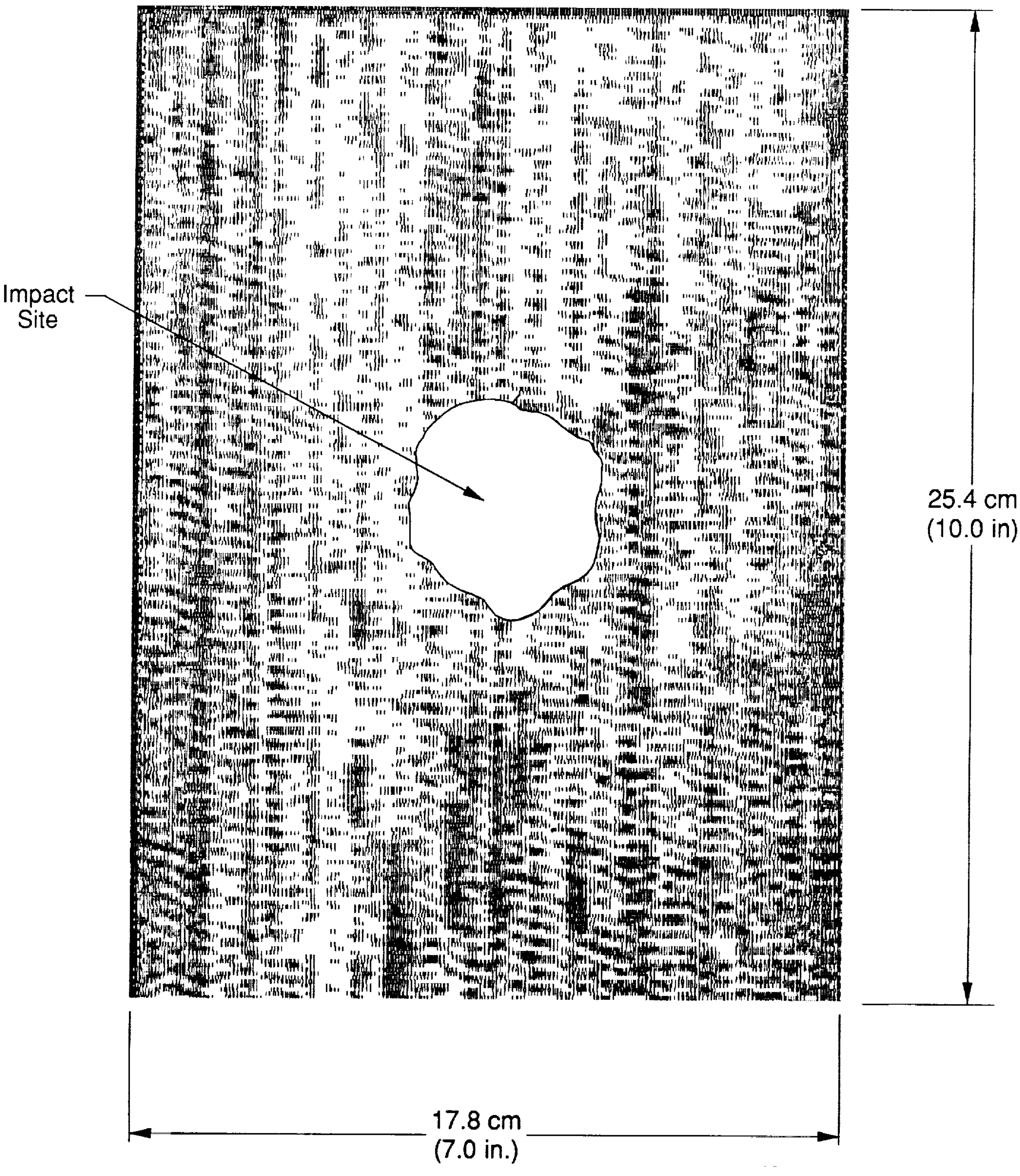


Figure 18: C-Scan of Post Impacted Stitched AS4/3501-6

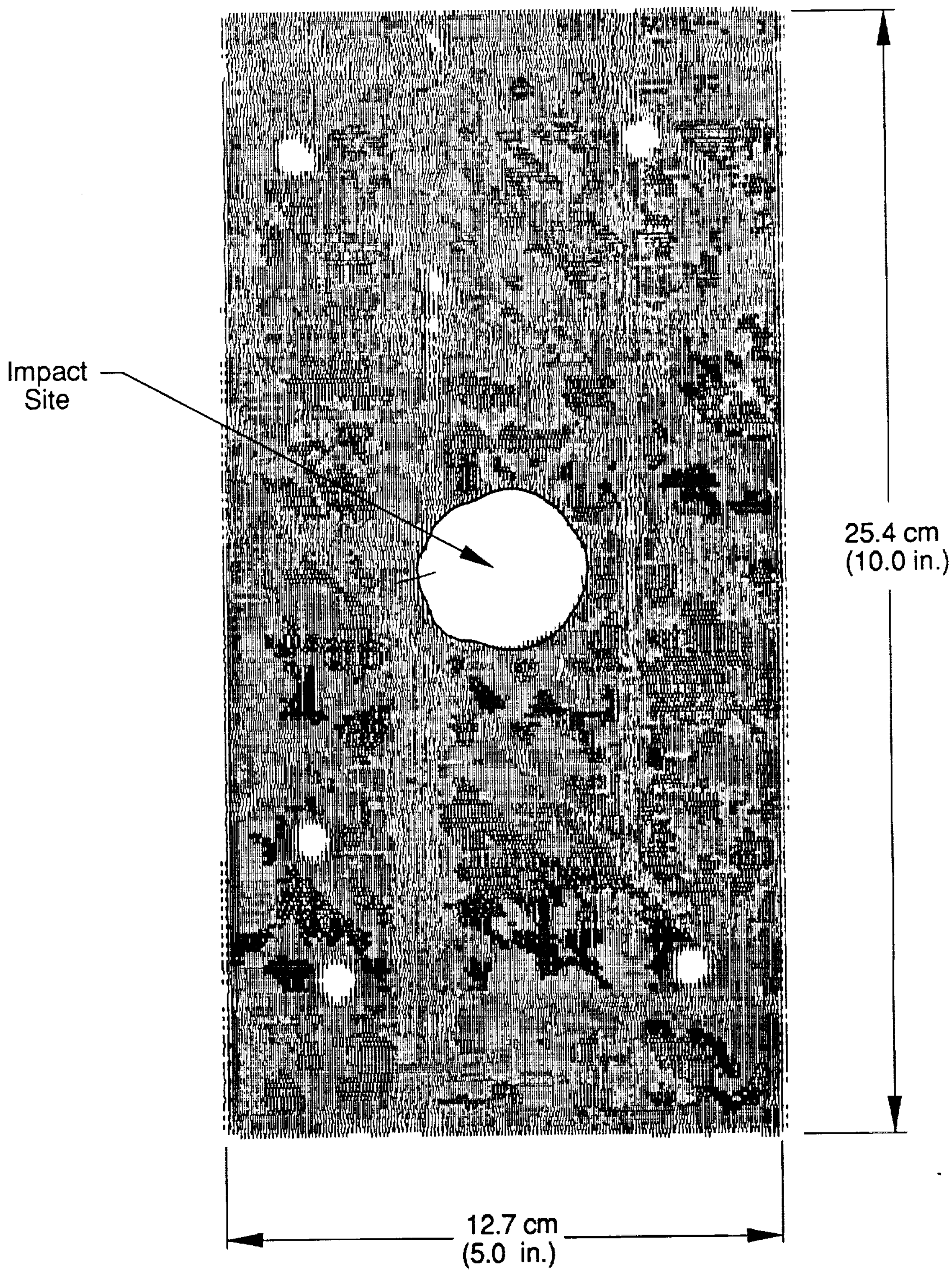


Figure 19: C-Scan of Post Impacted IM7/8551-7

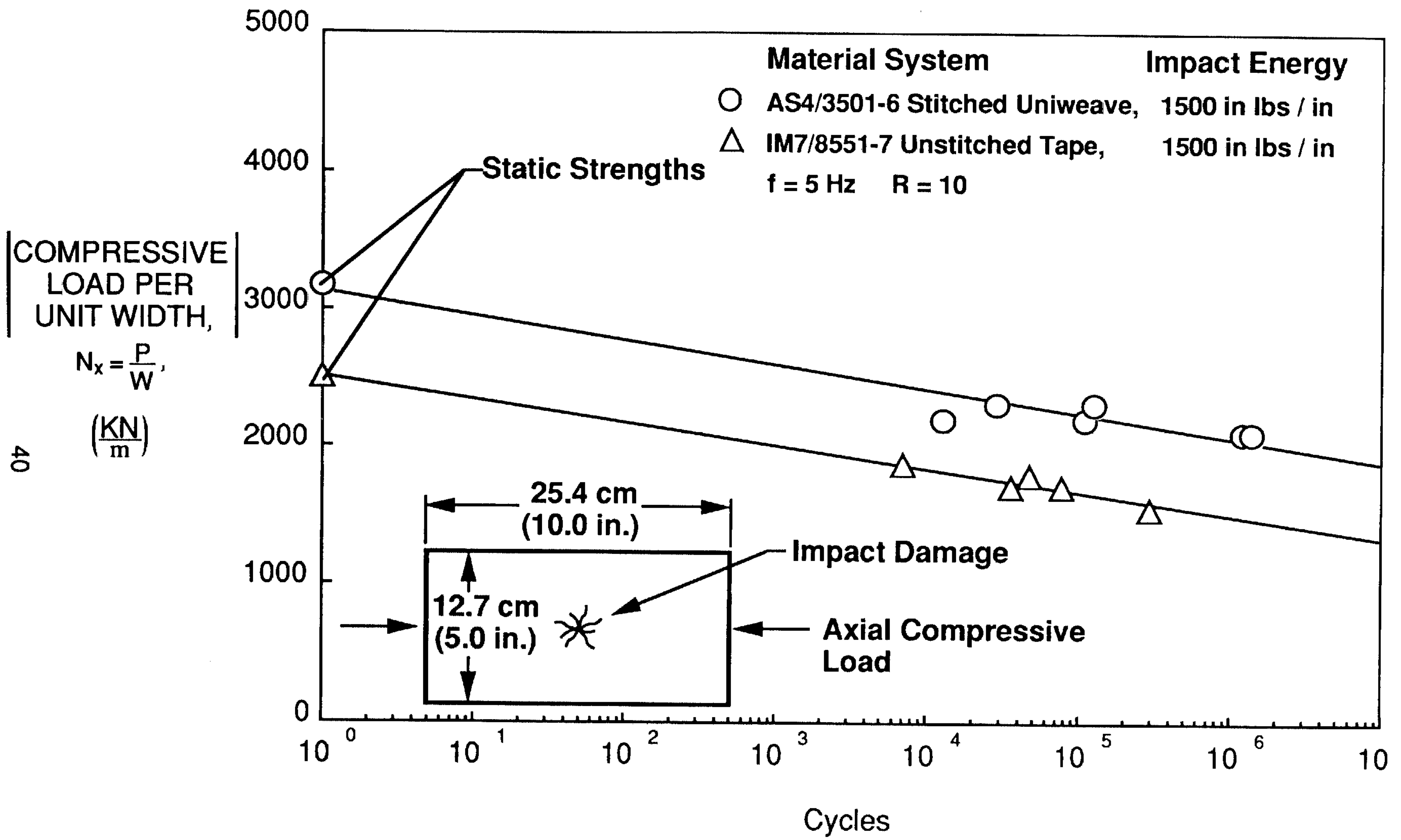


Figure 20: A Plot of Load per Unit Width versus Cycles for Post Impact Specimens

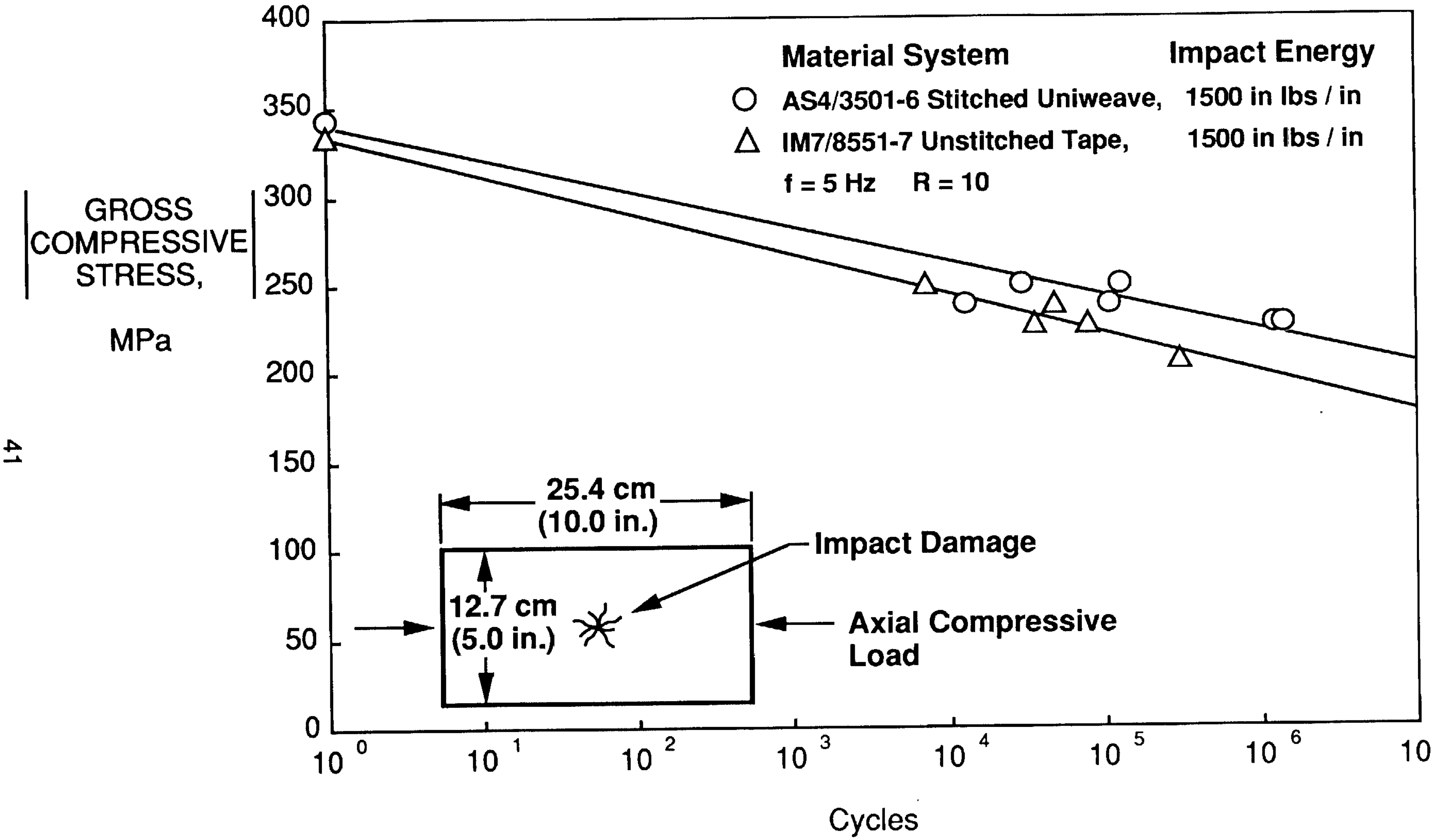


Figure 21: A Plot of Gross Compressive Stress versus Cycles for Post Impact Specimens

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15. Supplementary Notes

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16. Abstract

This investigation evaluates the performance of a stitched uniweave fabric composite and that of a toughened tape composite. Further, it addresses the effects of stitching on compression fatigue life. Post impact compression fatigue and open hole fatigue tests were run on an AS4/3501-6 uniweave with stitching and a toughened IM7/8551-7 tape without stitching. Stitching was found to increase the thickness and consequently the weight of the composite material. The two materials were compared on an equal carbon content basis as well as on an equal weight basis. The excess thickness in the stitched uniweave composite was responsible for the lower fatigue life, on an equal carbon basis, compared to the toughened resin tape composite. Comparison of fatigue lives on an equal carbon content basis indicated that puncture or crimp type damage from stitching has very little effect on compression failure. Post impact fatigue tests showed that although the damage area in the stitched uniweave composite was twice that of the toughened tape composite, the fatigue lives of the stitched composite were significantly longer than those of the toughened composite. Thus, it appears that the increase in thickness from stitching is much more of a penalty than crimped fibers or puncture type damage from stitching.

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